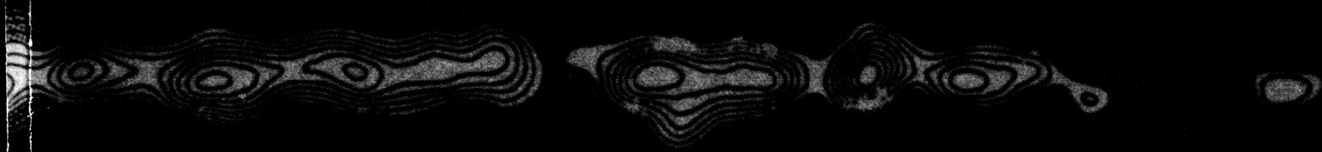
Messengers of Creation

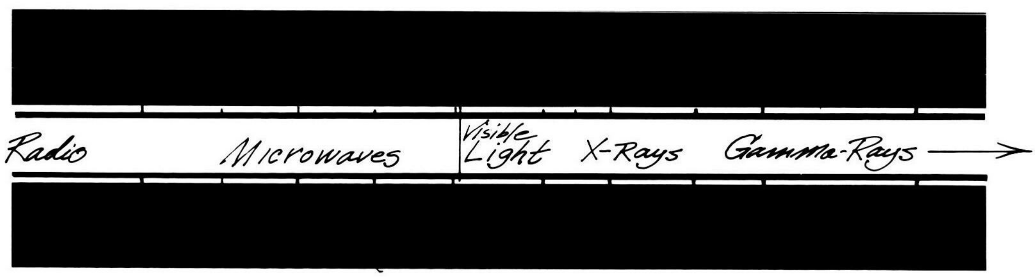


The gamma-ray sky as seen by the COS-B satellite.

The NASA Gamma-Ray Observatory Mission

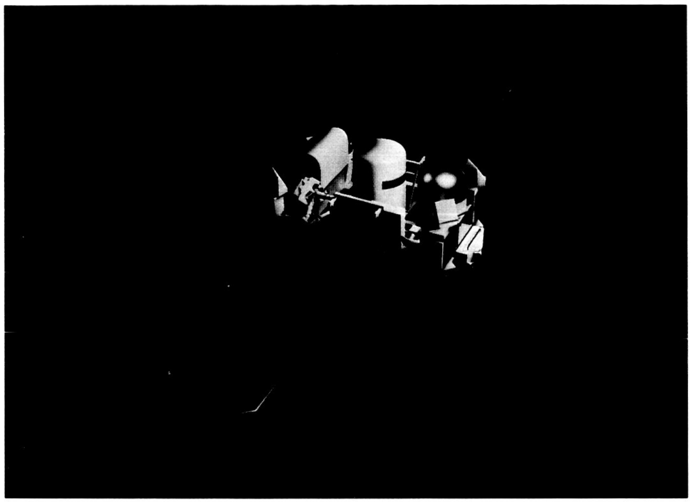
Astronomy is useful because it raises us above ourselves; it is useful because it is grand;... it shows us how small is man's body, how great his mind. His intelligence can embrace the whole of this dazzling immensity, in which his body is only an obscure point, and enjoy its silent harmony. Thus we attain self-insight, something which cannot cost too dear, since this insight makes us great.

Henri Poincaré, 1903



The Electromagnetic Spectrum. Energy at any point of this spectrum takes the form of photons, or quanta of energy, that travel at the speed of light. Only those in the relatively narrow portion of the spectrum we call visible light are detectable by our eyes. Many stars radiate energy over the entire spectrum, and we can learn much about them by detecting their nonvisible radiations. We have just begun to explore the possibilities of gamma-ray astronomy to add to our knowledge derived from the radio, infrared, visible, ultraviolet, and X-ray parts of the spectrum.

Foreword



Artist's rendering of the Gamma-Ray Observatory in orbit.

As far back in history as we know, and in all parts of the earth, man has looked at the heavens and tried to understand what he sees. What are those celestial objects? Why are there different kinds (sun, moon, stars, planets)? Why do they have different motions? Why are some stars brighter than others?

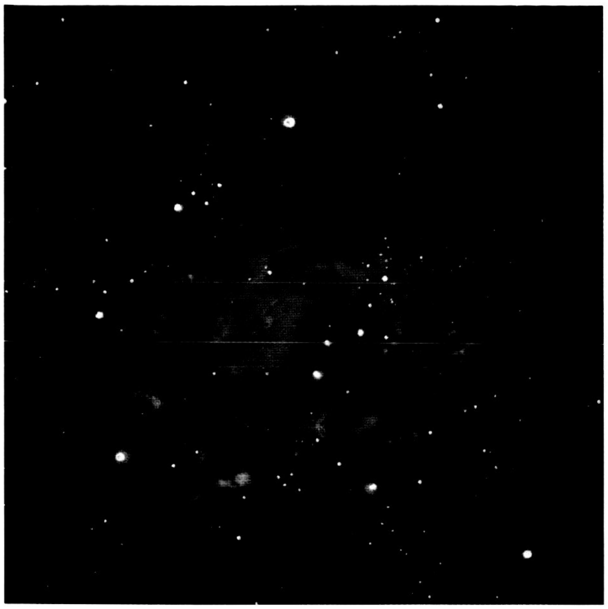
With the advent of the telescope and the work of Galileo, Copernicus, Newton and Einstein, astronomers began answering some of these questions. The development of nuclear physics has provided answers to others. With each new development, however, we have found more questions to ask. We found that the stars (including our own sun) send out kinds of energy that we cannot see, such as infrared and ultraviolet radiation. More recently we found that they also send out radio waves, X-rays, and gamma rays. Each of these parts of the spectrum tells us something new about the stars, and combined observations at multiple wavelengths have answered questions that no single kind of observation can.

With these advances in technology, astronomers, astrophysicists and cosmologists have developed new theories about what is going on in the universe. We have come to understand that stars are not everlasting, but are born, age and die. Using Einstein's theories and our knowledge of nuclear physics, we can describe the processes that cause the birth, aging and death of stars. After theoretical astrophysicists develop these models on the basis of observations, experimental astrophysicists try to confirm them by more observations.

Each part of the spectrum has its own contributions to make to our understanding of the universe. The gamma-ray portion of the spectrum, reflecting the highest energy processes, will be especially rich in information on the evolution of stars and of the universe. Gamma-ray observations will let us test whether the laws of physics work the same under the unimaginable conditions of pressure, gravity and magnetic force that exist elsewhere in the universe.

The Great Nebula in Orion. This object, visible to the naked eye, is a giant cloud of gas and dust with several young, hot stars at its center. Clouds like this are believed to be the birthplaces of stars. The Orion Nebula is an extended source of gamma rays. Detailed study of this region by the GRO instruments should help us learn more about conditions in regions of star formation.

The Violent Universe—I



The Crab Nebula. This object is a supernova remnant with a pulsar near its center. Detailed gamma-ray observations will help to unravel the processes by which supernova explosions form pulsars and emit large amounts of radiation long after the initial explosion.

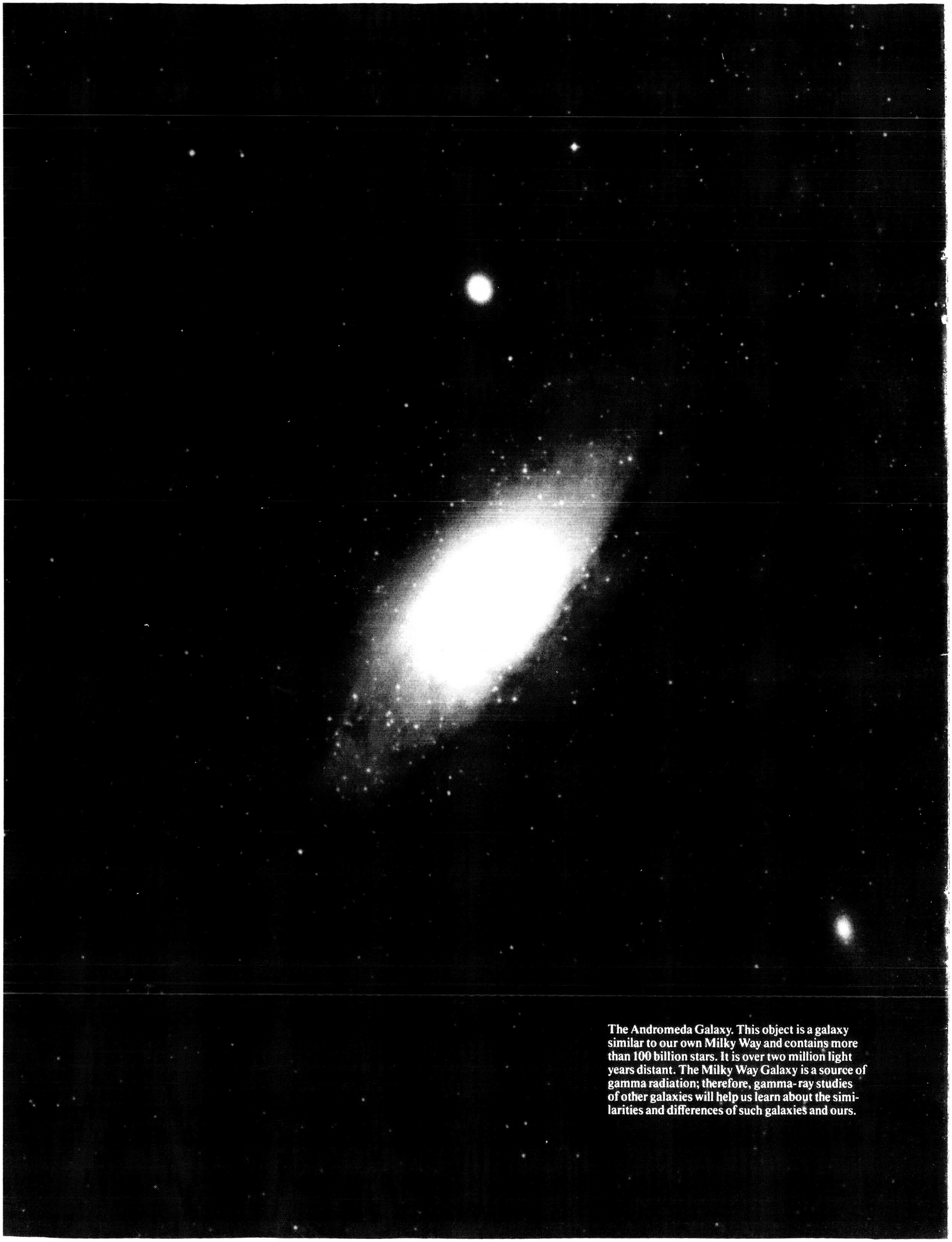
The night sky has always symbolized a calm, indifferent, unchanging universe within which we play out our eventful lives. Now that we have looked at the sky with new eyes made possible by advancing technology, we know that those immutable stars are in fact the scenes of violent, sometimes catastrophic, activity. Stars collapse into white dwarfs and neutron stars, where the force of gravity is so great that it crushes atoms and, theory tells us, they eventually collapse into black holes from which not even light can escape. Stars explode into novas and supernovas. Quasars emit energy at all wavelengths at rates equal to a thousand galaxies and seem to be receding at velocities approaching the speed of light. All is not calm and unchanging out there.

By observing gamma rays from the most distant quasars, we may be looking back billions of years in time and seeing the universe before our solar system existed. We may see that during the earliest years of the universe there are physical phenomena that are not yet understood.

Pulsars were first discovered by radio astronomers in the 1960s. They radiate energy in pulses, which suggests that the energy comes from a rotating body of enormous density and magnetic field and very small size such as a neutron star. At least some pulsars, even though they were discovered by their radio emissions, radiate a hundred thousand times as much energy at gamma-ray wavelengths. Detailed gamma-ray observations may reveal the secrets of that colossal energy emission.

The death of a star, if its size is a few times that of our sun, may take the form of a supernova. This is the explosion of the star after it has consumed all its nuclear fuel, blown off its envelope, and collapsed into a neutron star. These extreme conditions create elements heavier than iron. The lighter elements are formed by the more conventional nuclear processes in stars. Much of the matter in our everyday world is made only in this way. Gamma-ray observations of young supernovas will show us these processes in action.

This artist's rendering of an exploding galaxy shows another of the violent events that we hope to explore with gamma-ray astronomy to improve our understanding of the violent universe.



The Andromeda Galaxy. This object is a galaxy similar to our own Milky Way and contains more than 100 billion stars. It is over two million light years distant. The Milky Way Galaxy is a source of gamma radiation; therefore, gamma-ray studies of other galaxies will help us learn about the similarities and differences of such galaxies and ours.

The Violent Universe—II

Black holes have become a household word even though none has ever been observed. Cosmologists believe that a large number of mini-black holes may be left over from the original Big Bang. If we can prove they exist, then we will be closer to understanding how our universe began.

One way to identify a black hole will be through gamma-ray observations, because the processes in the vicinity of a black hole will generate gamma rays of specific energies. We know what to look for, but only with instruments observing from beyond earth's atmosphere can we find the evidence we seek.

One theory suggests that the Big Bang left globs of antimatter in the universe. If these globs exist, we know the annihilation radiation, resulting from the interaction with ordinary matter, will contain a certain identifiable set of gamma rays.

Other interesting and evidently violent objects we would like to look at extensively in the gamma-ray spectrum are the "active" galaxies. Quasars are one type. It has been suggested that all types may have massive black holes at their centers. Another type is the Seyfert galaxy, which emits far more energy than a normal galaxy and varies in brightness for unknown reasons. It is expected that Seyfert galaxies emit gamma rays in addition to the X-rays so far observed; as yet, we have been unable to confirm this theory.

Another type of active galaxy is the radio galaxy; it seems ordinary in visible light but emits large amounts of radio energy at a varying rate. At least one radio galaxy has been observed to emit X-rays and gamma rays, but more observations are needed to determine whether there are others and what processes are generating the energy. The same is true of the other type of active galaxy, the BL Lacertae objects. They too are variable, emit both radio and X-rays, and are expected to be gamma-ray sources.

One of the most puzzling violent objects is the gamma-ray burster. Something is occasionally emitting bursts of gamma-ray energy, but so far no source has been identified with any other known object. One possible exception is the unusual burst observed in 1979. Unlike others, it showed a series of pulses at eight-second intervals for almost three minutes. By a bit of luck, it was observed by several spacecraft, and it could be determined that the burst came from the direction of a known object, the Large Magellanic Cloud. It may not have originated there, but if it did, it emitted more energy in a tenth of a second than our sun does in 10,000 years. This observation presents a quandry for astrophysicists, who currently have no accepted explanation for it. It also appears that there are different types of gamma-ray bursters which may be entirely different objects.

This artist's rendering of a black hole (which is in reality not detectable in visible light) suggests how matter and even photons of energy are sucked in by the enormous gravitation of a black hole. We hope that gamma-ray observations can tell us more about the processes thought to occur in the vicinity of a black hole and thus help to locate such objects.

For most of man's history, we have looked at the stars with the naked eye. Some cultures developed aids that enabled them to measure with high accuracy the motions of celestial objects. Only with the development of the telescope in recent times (recent in terms of human history) could we see such details as Saturn's rings and the moons of Mars. As telescopes improved we could see details beyond the solar system, such as spiral galaxies. Only yesterday (less than 50 years ago) did we begin to explore the universe at invisible wavelengths. First came radio astronomy, and then with satellites we could get outside the atmosphere to look at the universe in the infrared and ultraviolet, in X-rays, and finally in the enormously wide gamma-ray region that promises answers to many of our questions about how the universe works.

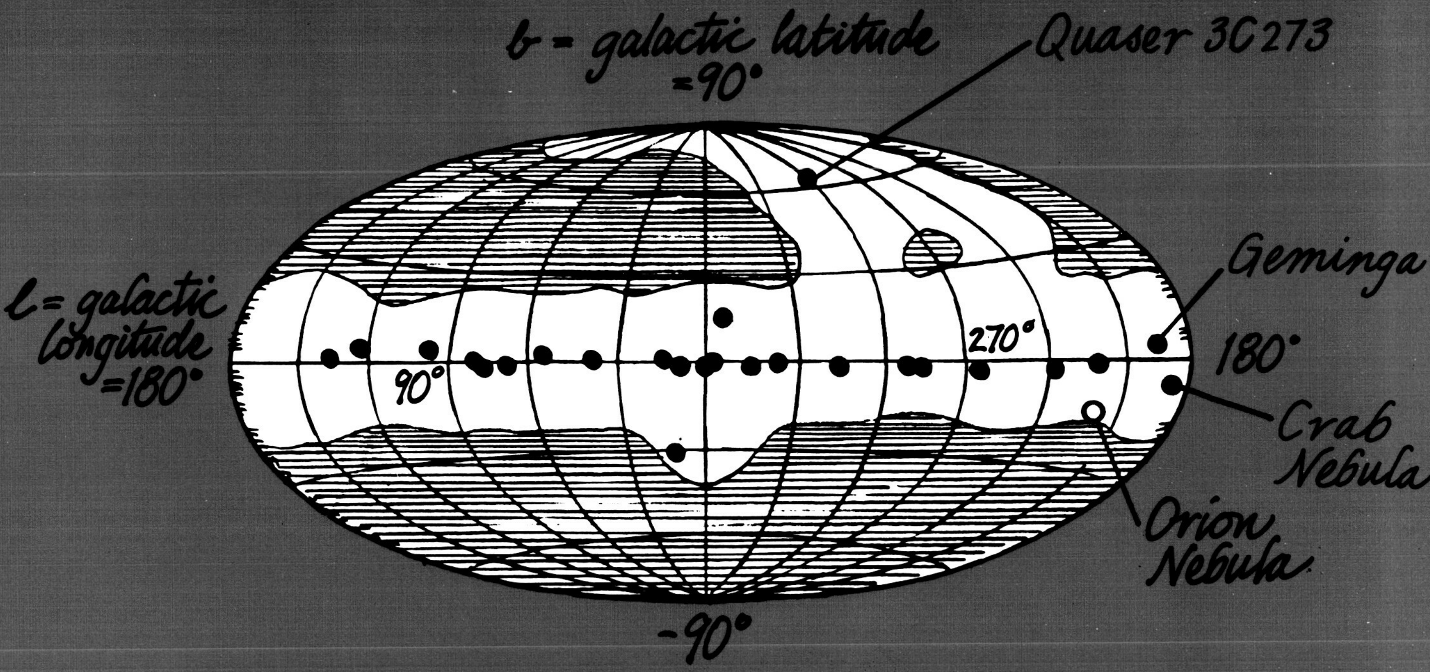
The New Astronomy

Astronomers have been able to learn a great deal about the universe by looking at it in the narrow part of the electromagnetic spectrum that we call visible light. They have determined its general structure and formed theories about its history. Since shortly before World War II, however, they have been looking at the universe in new parts of the spectrum. Radio astronomy was the first of these extensions, made possible by the transparency of our atmosphere to a large band of radio wavelengths.

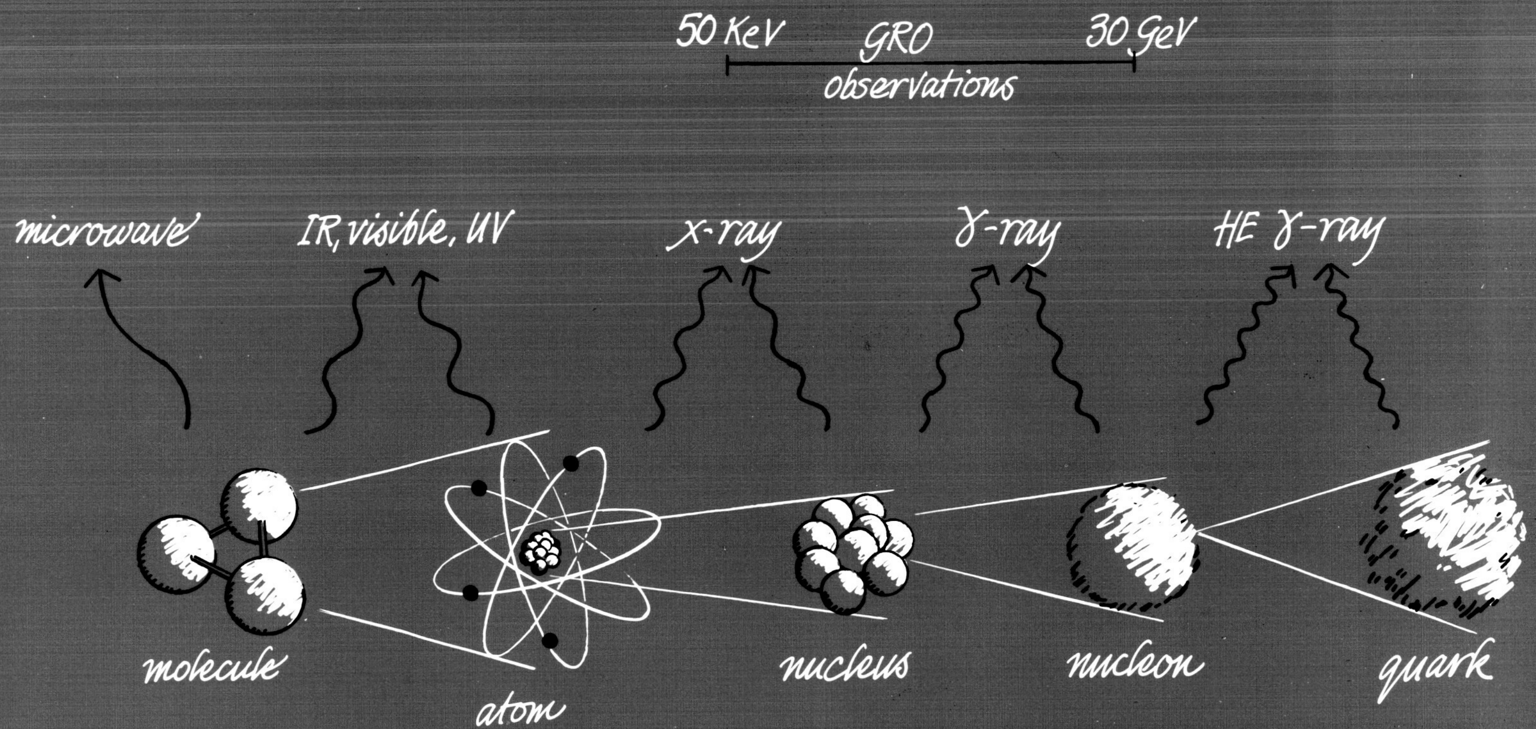
Except for visible light and radio waves, the atmosphere is largely opaque to wavelengths, including gamma rays. Balloons and rockets above the atmosphere have been useful for such observations over short periods. For the first time, earth-orbiting satellites have made it possible to conduct long-term observations outside the atmosphere. The results from satellites looking across the wavelength spectrum have sent the theoreticians back to their blackboards. With a highly capable gamma-ray observatory, a new window of the universe will now be open.

Today's technology has enabled us to build larger and more sophisticated scientific satellites, with each step yielding an increasingly accurate and detailed picture of what is going on in the universe. Now with the advent of the Space Shuttle we can launch the very large and complex orbiting observatories needed to increase the quality and accuracy of our observations. The Hubble Space Telescope with its eight-foot mirror is the first of these. The Gamma-Ray Observatory (GRO) will be the second. The advantage of size is especially important for gamma rays because they are relatively sparse, and large instruments are needed to collect significant numbers of gamma-ray photons in a reasonable period of time. They cannot be focused to form images and can be detected only indirectly, by their interaction with matter in the detector.

Several relatively small gamma-ray detectors have been flown on earlier satellites and have given us the first tantalizing glimpses of the wealth of information available from gamma rays. Their results have raised a host of questions that can be answered only by the larger, more sophisticated instruments on the Gamma-Ray Observatory.



This map of the sky in galactic coordinates shows the locations of gamma-ray sources observed to date, principally by the small SAS-2 and COS-B satellites. A large part of the sky, the shaded region, remains to be explored in detail. The locations of a gamma-ray-emitting quasar (3C273), the Crab Nebula, and the Orion Nebula are shown, along with a mystery source called Geminga, which has not yet been positively identified in any part of the spectrum except gamma rays.



Excited molecules emit radio waves as they relax from the excited state, with the wavelength decreasing as the energy increases. Additional excitation energy excites infrared radiation, which blends into visible light as the electrons in the electron cloud around the nucleus are raised to excited states and relax. When the energy goes beyond the ultraviolet range, the exciting energy raises the electrons to still higher states and X-rays are emitted. As the energy goes still higher, it penetrates the electron cloud and excites the nucleus itself, which emits gamma rays. Beyond this range, the individual nucleons (protons and neutrons) in the nucleus become excited and emit higher energy gamma rays. We expect that excitation beyond this point may penetrate the nucleon and excite its constituents, the elusive quarks, and reveal some of their secrets as they emit extremely high-energy gamma rays.

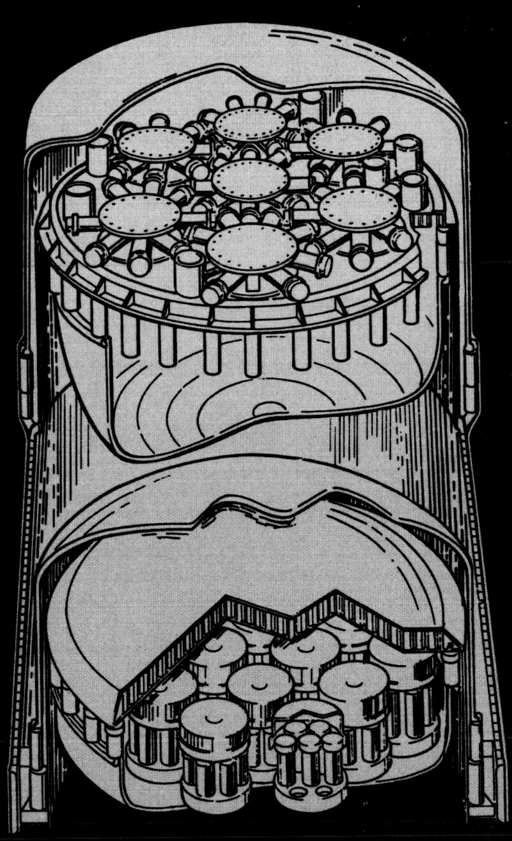
Gamma Rays

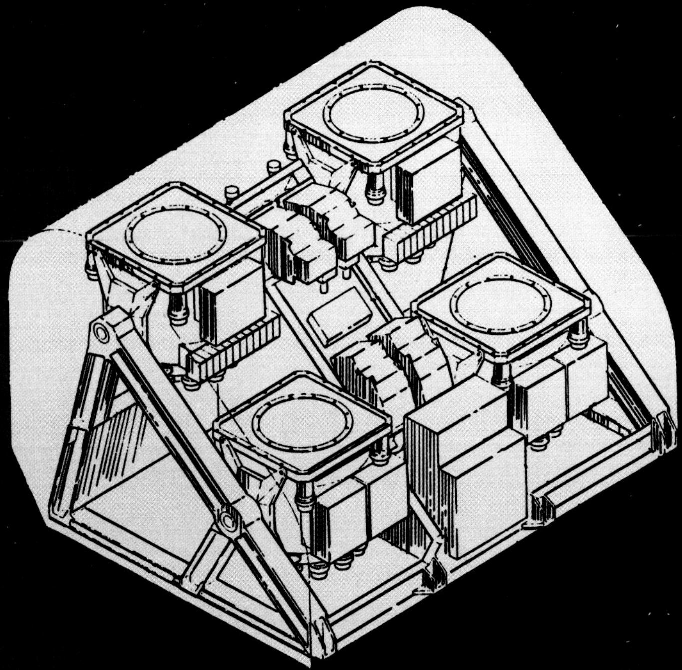
Gamma rays are a form of electromagnetic radiation, like radio waves or light rays or X-rays, but with shorter wavelength and therefore higher energy. All these forms of radiation have properties of both waves and particles. The particles are packets of energy (photons). Lower-energy photons are emitted when an electron changes energy level in its atom, but gamma-ray photons are emitted when the nucleus of an atom changes energy level. Photons are also emitted when a high-energy electron interacts with matter, with a strong magnetic field, or with other, lower energy photons. Gamma-ray photons are also created when matter and antimatter meet, as when a positron and an electron meet and annihilate each other.

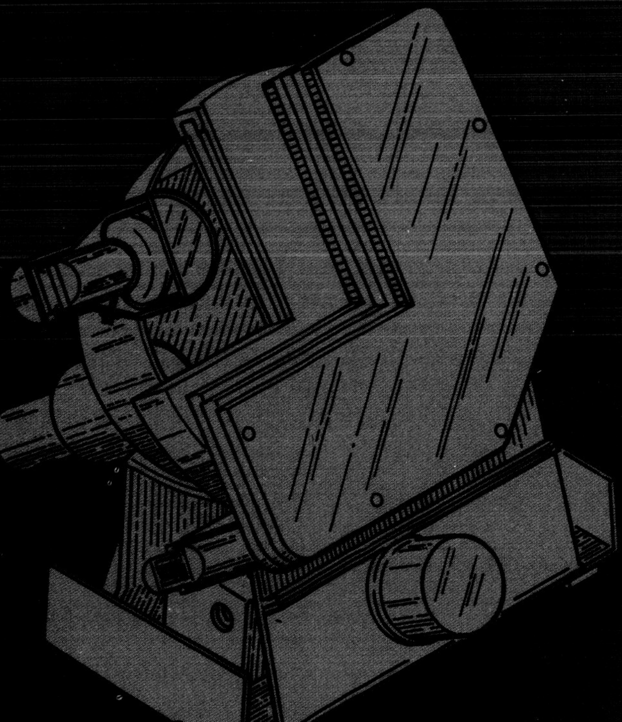
All these processes are going on in the universe, and each produces gamma rays with characteristic energies or a flux of gamma-ray photons with characteristic spectral shape. The excited nucleus in an element deactivates to lower energy levels and emits a gamma-ray photon, characteristic of the specific element. Gamma-ray astronomy is so important because it can tell us what processes created the photons and what kinds of atoms were involved.

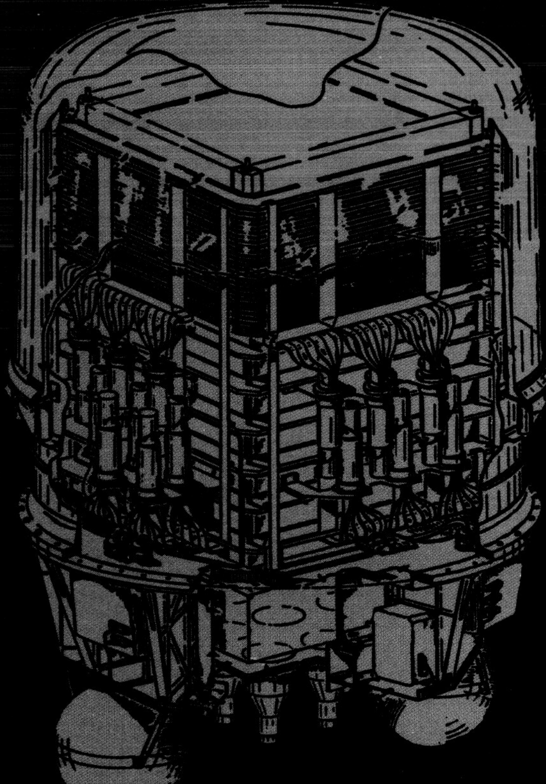
Because of the extremely short wavelength of gamma rays, we do not discuss them in the common terms of wavelength or frequency but use an equivalent measure, energy. Visible light measured in these terms has an energy in the range of one electron volt, while the lowest-energy gamma rays begin at a tenth of a million electron volt. There appears to be no upper limit to the energy of gamma rays.

Gamma rays are truly messengers of the creative events in our early universe. The universe is largely transparent to gamma rays. They can reach our detectors from the remotest parts of the universe without losing energy or being deflected. Other forms of radiation tend to be dispersed by interstellar matter; for example, we cannot "see" the center of our own galaxy at other wavelengths because of all the intervening matter. The Gamma-Ray Observatory will help us find out what is at the center of the galaxy and what is going on there.









The Gamma-Ray Observatory

The gamma-ray part of the spectrum is much larger than the other parts such as radio waves or light or X-rays. The range of energies is over ten thousand times that of visible light and over a hundred times that of X-rays.

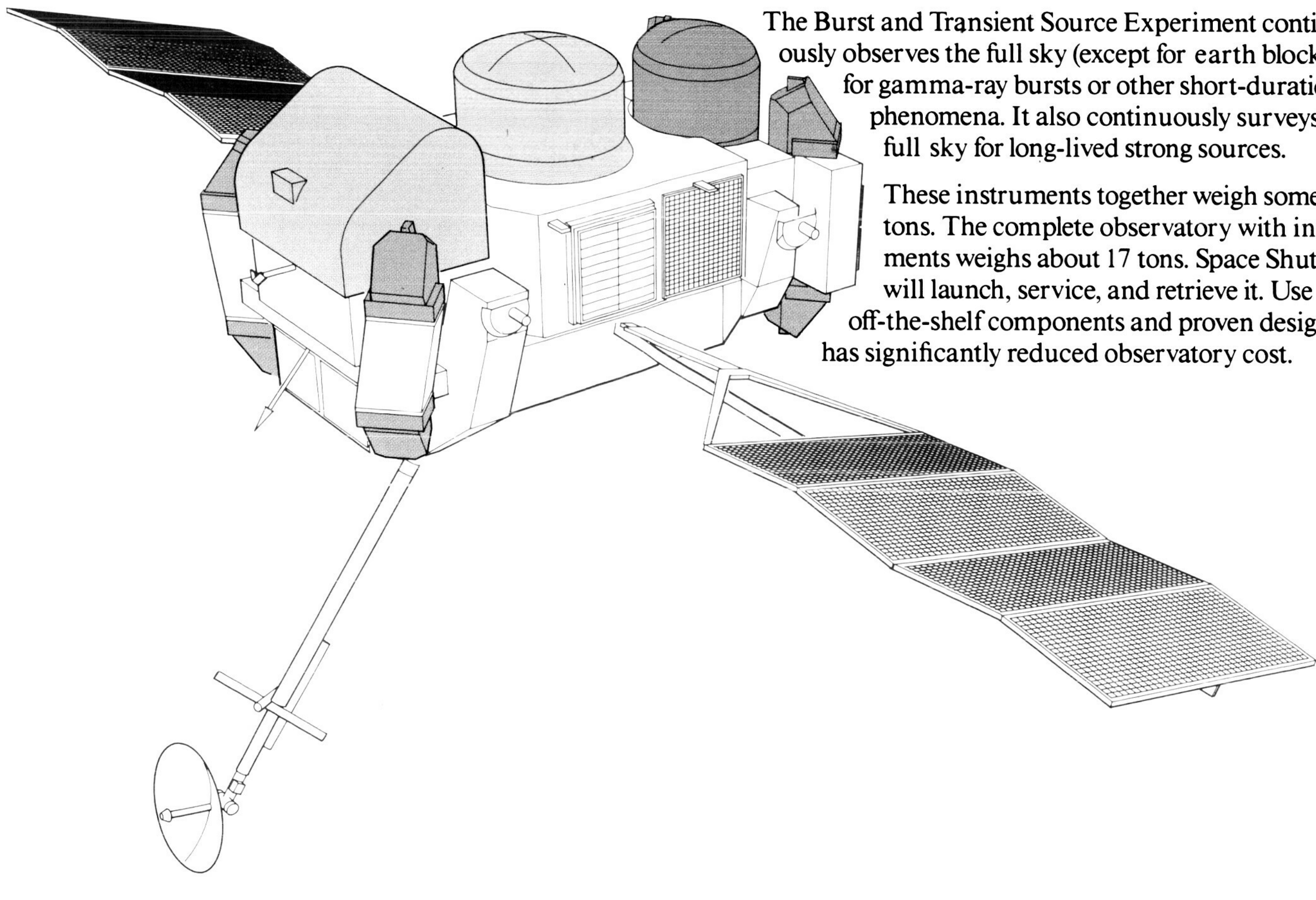
The Oriented Scintillation Spectrometer Experiment observes the low-energy range from a tenth of a million to 10 million electron volts. Four separate, rotating detectors look at different parts of the sky. With this arrangement, the background radiation can be measured and then subtracted from the measurements of a point source. This instrument is over 10 times more sensitive than any previously flown unit. It determines the direction of a source to a fraction of a degree.

The Imaging Compton Telescope, called Comptel, is the mid-range instrument. It covers the range from one to 30 million electron volts and determines angle of arrival to within less than a degree at the higher energies. It measures the energy of the photons to within 5 percent (also at the higher energies). Special provisions reduce the background radiation effects.

In the highest energy range, above 20 million electron volts, the Energetic Gamma-Ray Experiment Telescope measures the position of a source to a fraction of a degree and the energy of individual photons to within 15 percent.

The Burst and Transient Source Experiment continuously observes the full sky (except for earth blockage) for gamma-ray bursts or other short-duration phenomena. It also continuously surveys the full sky for long-lived strong sources.

These instruments together weigh some six tons. The complete observatory with instruments weighs about 17 tons. Space Shuttle will launch, service, and retrieve it. Use of off-the-shelf components and proven designs has significantly reduced observatory cost.



The Mission of the Gamma-Ray Observatory

Astronomers and astrophysicists are looking forward eagerly to the launching of the Gamma-Ray Observatory which is designed to collect far more and better gamma-ray data than has ever before been possible. They have enough jobs lined up for it to keep it busy for many years. The earlier gamma-ray observations have raised dozens of questions that can be answered only by the high-sensitivity, high-resolution observations GRO is being built to make.

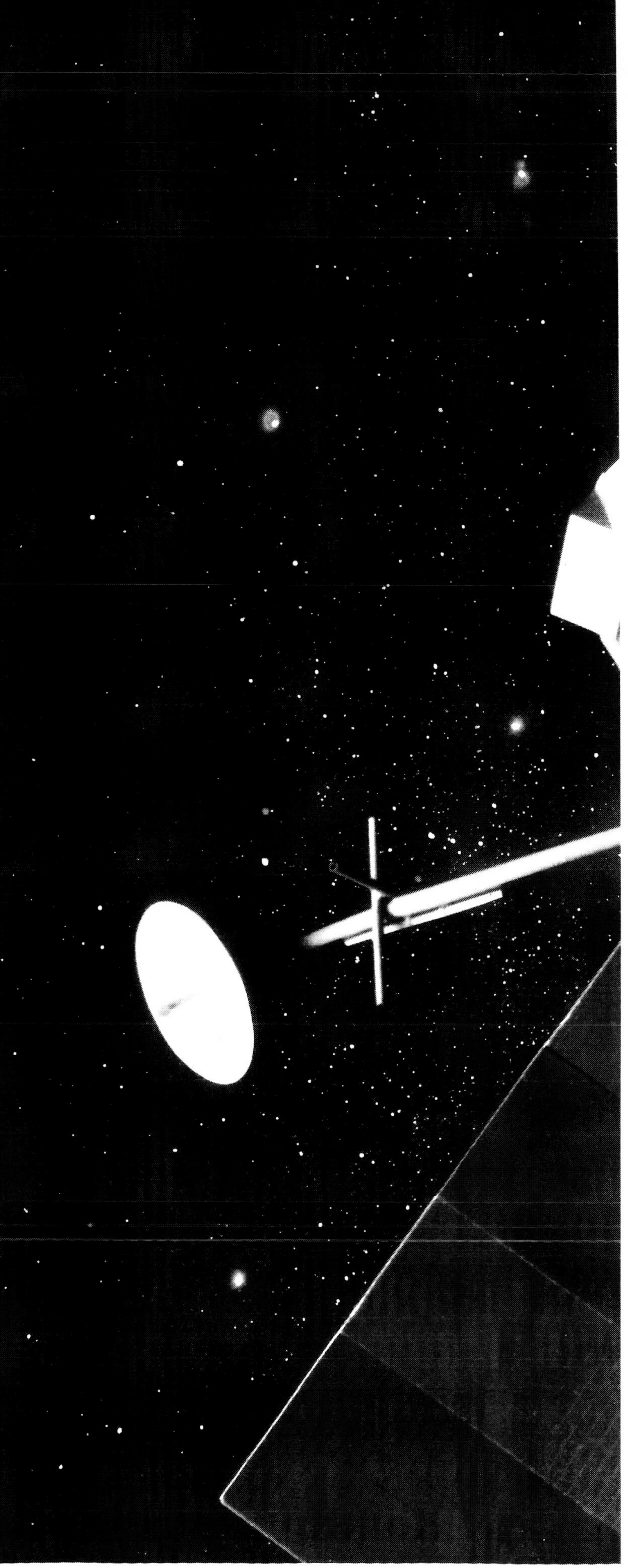
For example there is a diffuse flux of gamma rays that seems to be coming from all directions. Some of it probably comes from interactions of fast-moving protons (and a few electrons) called cosmic rays, which seem to be coming from all directions. When they encounter matter in the form of interstellar dust or gas, the interaction can produce gamma rays. The energy of these gamma rays can tell us about the characteristics of the cosmic rays and the matter they encountered. One thing we hope to learn is whether the cosmic rays are really coming uniformly from all directions or have regional sources of higher and lower intensity.

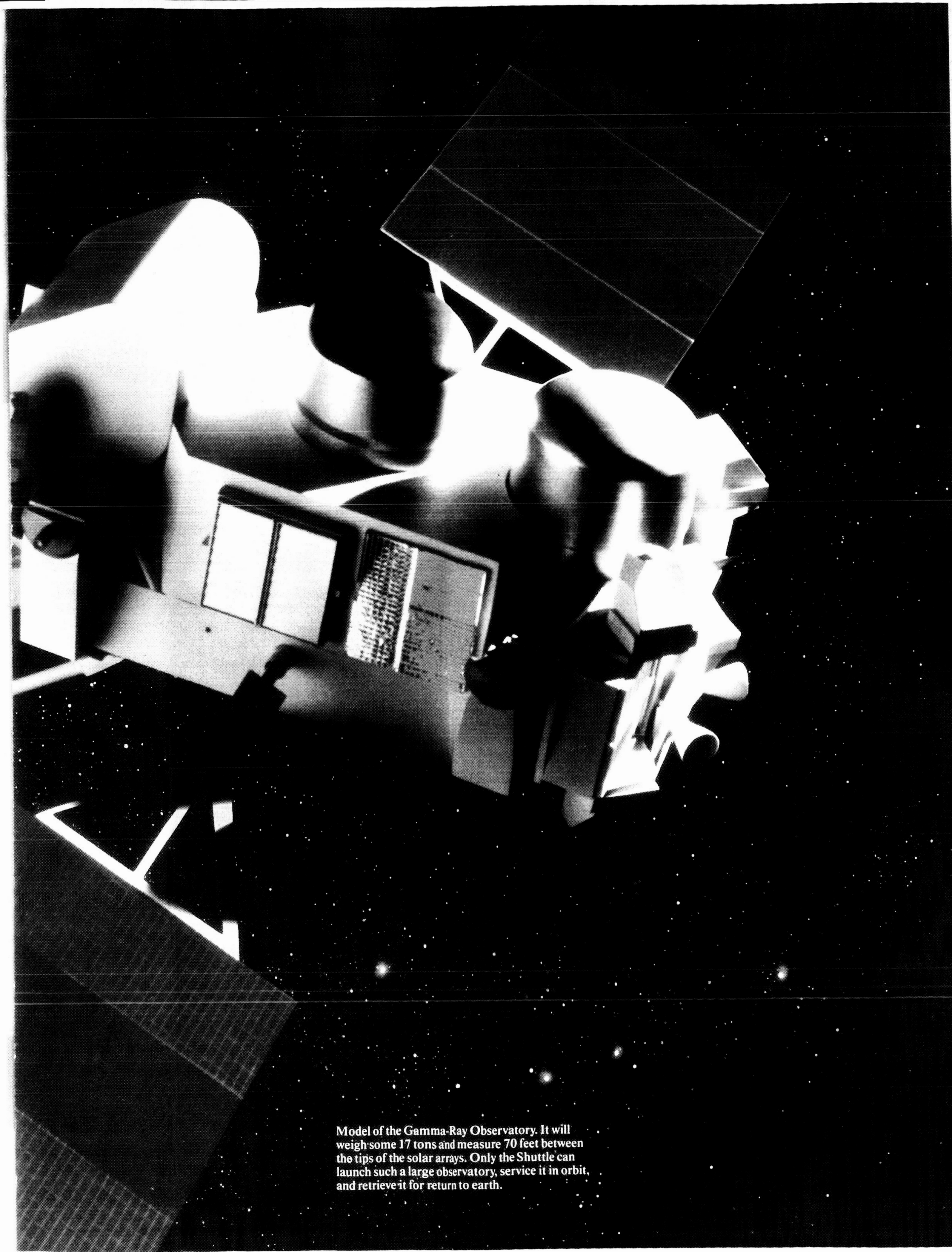
GRO's data will tell us about the nature and distribution of matter. We are especially interested in the center of our galaxy, which is obscured at other wavelengths by clouds and dust.

Probably first on the target plan for the GRO are the point sources of gamma radiation that have already been observed, particularly the supernova remnant in the Crab Nebula in our galaxy. High-resolution gamma-ray observations may help us understand how the heavier elements are formed in such supernovas.

Quasars, pulsars, and active galaxies are high on the list because of the unusual and poorly understood nature of these objects. And the list goes on. It includes our own sun, which is also a source of gamma rays. GRO has special provisions for solar observations. The plan is that the GRO will, in addition to observing many known sources, make the first full-sky, gamma-ray survey of the heavens.

These messengers of creation will tell us some things we expect. They will probably tell us many things we did not expect. It has always turned out that way.





Model of the Gamma-Ray Observatory. It will weigh some 17 tons and measure 70 feet between the tips of the solar arrays. Only the Shuttle can launch such a large observatory, service it in orbit, and retrieve it for return to earth.

What Good is Gamma-Ray Astronomy?

When the apple fell on Newton's head and inspired him to make the connection between falling objects and the motions of heavenly bodies, this was an early example of the discovery that processes familiar to us on earth are in fact universal. Newton could not have made that connection if he had not been familiar with current astronomy, particularly the work of Copernicus and Kepler.

Since then, and especially since the advent of spectroscopy in the 19th century, many more such connections have been made between processes on earth and those in the heavens. The hydrogen line in a spectrum is in the same place whether it is produced by a man-made flame or by a star millions of light-years distant. Such astronomical spectroscopy has brought us an understanding of stellar processes and served as the foundation of astrophysics. At the same time, astrophysical observations have made us refine our theories of energetic processes.

Einstein's relativity theory was confirmed by astronomical observations before it was applied to the development of nuclear energy for human use. The prediction of the existence of black holes is based on Einstein's work, which also accounts for the observations of novas and supernovas and other cosmic processes.

This interchange between astronomical observations and our theories about physical processes continues. Observations either confirm theories or lead us to refine them to account for the observations. More observations are then needed to check the revised theory.

Gamma-ray astronomy has already made contributions to this process, even with the relatively crude observations made so far. The gamma-ray portion of the spectrum is expected to make very large contributions to our understanding of physical processes in the cosmos, not least because it is such a large segment of the total electromagnetic spectrum. Experience shows that an understanding of physical processes in the cosmos leads to improved understanding of the same processes in our own environment.

Apples fall in accordance with the same laws that make (we think) black holes.

Albert Einstein as a young man. His most important works, the Special Theory of Relativity and the General Theory of Relativity, were published during the early years of his career.

The HEAO-3 spacecraft gamma-ray spectrometer observed and identified gamma rays associated with the decay of the Aluminum-26 isotope. Because this isotope has a lifetime of only a million years (short on astronomical time scales), the material must have been produced in our galaxy in the very recent past. This direct gamma-ray evidence that the process of element building is continuing today was considered of sufficient importance to be cited by William Fowler in his Nobel Prize acceptance speech. Results from the Gamma-Ray Observatory should yield additional information of similar importance about our universe.

With its high-gain antenna and solar arrays stowed, GRO fits in half the length of the Shuttle cargo bay.

References and Additional Reading

The Amazing Universe, Herbert Friedman, National Geographic Society, Washington, D.C., 1975

"High-Energy Gamma-Ray Astronomy," Carl Fichtel, Kenneth Greisen, and Donald Kniffen, *Physics Today,* September *28,* 1975

"Gamma-Ray Astronomy: Through a Glass Darkly," David J. Thompson, *Griffith Observer, 43,* January 1978

A Strategy for Space Astronomy and Astrophysics for the 1980s, Space Science Board, Assembly of the Mathematical and Physical Sciences, 1979

"Gamma-Ray Line Astronomy," Marvin Leventhal and Crawford J. MacCullum, *Scientific American, 243,* July 1980

"Second COS-B Catalog of High-Energy Gamma-Ray Sources," B.H. Swanenburg, et al., *Astrophysics Journal, 243,* January 15, 1981

"Gamma-Ray Observatory to Explore a Violent Universe," James Kurfess and Neil Johnson, *Astronautics and Aeronautics,* January *19,* 1981

Gamma-Ray Astrophysics: New Insight into the Universe. Carl E. Fichtel and Jacob I. Trombka, National Aeronautics and Space Administration, Washington, D.C., 1981

Astronomy and Astrophysics for the 80s, Volume I, Report of the Astronomy Survey Committee, National Academy Press, 1982

The Star Splitters, W. Tucker, 1982

Gamma-Ray Astronomy, Hillier, Oxford U. Press, 1984

The Cosmic Inquirers, Tucker & Tucker, Harvard University Press, 1985

The Great Observatories for Space Astrophysics, NASA Astrophysics Division, Washington, D.C., 1985

High Energy Astrophysics, F. Lamb, ed., Benjamin/Cummings Publication Company, 1985

Gamma-Ray Bursts, Liang & Petrosian, ed., AIP Conference Proc. No 141, AIP Press, 1986

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Einstein	Frank L. Warren

"The more energetic the quanta we measure, the deeper we can observe, and thereby we can observe the most fundamental processes of nature in action. This is a wonderfully exciting thing to contemplate."

Robert Hofstadter

Max H. Stein Professor of Physics, Stanford University

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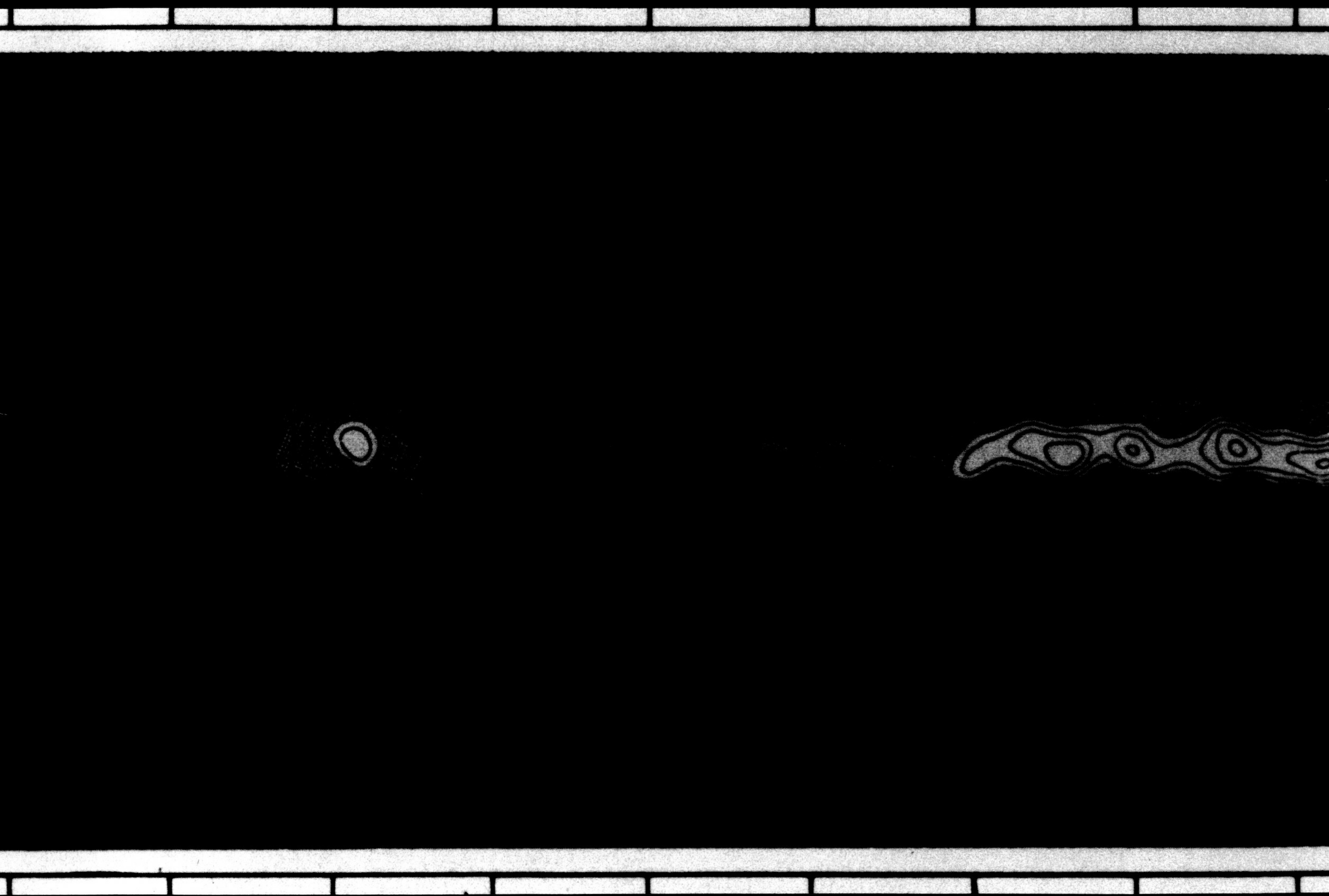

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